ECOLOGICAL ANALYSIS IN AND IN SUPPORT OF NAMM

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The purpose of the National Assessment Multiresource Model (NAMM) is (1) to organize pertinent information, thus defining opportunities to improve the future renewable resource situation from an ecological, economic, and social point of view; (2) to facilitate the flow of this resource information from the forest level through the regional level to the national level; and (3) to facilitate the translation of national resource management goals into specific regional plans, and from there into specific forest level plans. The NAMM is actually a hierarchy of models linked by flows of information (fig. 1).

An important aspect of the NAMM is that it is designed to undergo changes which will improve the overall operation of the system. Certain mathematical techniques can be applied to the component models to help identify those areas in which additional research could provide significant improvement in the level of accuracy at which the NAMM would operate. Thus, the NAMM should be considered an approach which will help direct its own improvement through time.

At the lowest level of the NAMM hierarchy are the primary models. These models are used to estimate the joint response to management prescriptions of economically important resources and other environmental variables. The results obtained from the primary models in response to a set of alternative management prescriptions forms a data base used by models in the next level of the hierarchy. Within NFS lands, the primary models will be used to provide information on subunits of the forests called analysis areas. Primary models will also be used to provide information on nonforest lands, although such information is expected to be much less specific than that for NFS lands.

The models of the next level of the hierarchy are economic models based upon mathematical programming techniques such as Linear Programming and Integer Programming. Examples of such models which have been used previously are FORPLAN and NIMRUM. Such models define the relationships between the management alternatives and their associated benefits, costs, and outputs. These models can be solved to give the best set of management prescriptions to be used in a particular forest in order to best achieve a particular objective. The set of management prescriptions defines one prescription for each analysis area in the forest, and can be called a forest-wide plan. Other plans for the forest are defined by using alternative objectives, inputs (such as budget levels) or constraints in the secondary model. For each forest-wide plan, the model provides a summary of costs, benefits, and outputs.

At the next level in the NAMM hierarchy are the Regional Alternative Generator (RAG) models, which are also economic models based upon mathematical programming techniques. These models are used to choose a plan for each forest within the region. The choices are made by considering the sets of costs, benefits, and outputs provided for each forest-wide plan by the secondary models. The set of forest-level plans chosen is that which best achieves an objective for the region as a whole. This set of forest-wide plans becomes a regional plan. Other regional plans may be defined by using alternative objectives, inputs, or constraints in the RAG models. A region-wide summary of costs, benefits, and outputs is provided by the RAG model for each regional plan.

The National Alternative Generator (NAG) is the model at the top of the NAMM hierarchy. It is functionally analogous to the RAG model; the NAG model is used to define the sets of regional level plans which best achieve objectives at the national level. For each objective stated, the NAG model provides a nation-wide summary of costs, benefits, and outputs. Once a national level alternative is chosen to be implemented, the NAG model identifies the best set of regional plans to use, each regional plan identifies the forest-wide plan to be used in each forest, and each forest plan identifies the management prescription to be applied to each analysis area within the forest.

The models above the level of the primary models are similar in both structure and function. These models share the characteristics of (1) being used primarily for economic rather than ecological analyses, (2) having no direct input of ecological data, (3) being based upon mathematical programming techniques, and (4) being used to aggregate information from lower level models across geopolitical boundaries. Because a review of the NAMM identified a similar set of problems in each of the higher level models, these models are grouped as secondary models. The problems identified for primary and secondary models are discussed below.

Primary Models

The purpose of the primary models is to provide quantitative estimates of the production of resources and other environmental variables in response to any proposed management prescription. It is only at the level of the primary models that ecological relationships are defined within the NAMM. Thus, these models must provide estimates which can be easily integrated into the NAMM analysis, and which have the greatest possible accuracy and precision. In order to achieve an integrated assessment, these models must be designed to provide

estimates of the joint production of economically important resources and any additional environmental variables which may be required for the consideration of constraints on management practices, such as those of the NEPA.

Primary models can assume a variety of forms. However, many problems can be avoided or simplified by utilizing well-defined conventions to provide a common framework for the models. One convention useful in the NAMM model is to have primary models define or describe relationships between easily recognized components of the system which contain, at any time, fixed measureable quantities. Such components are usually called state variables or compartments. For example, the state variables in a model of an analysis area could include the biomass of shrubs, the density of rodents, or the concentration of sediments in stream water. Another useful convention is to define management prescriptions only in terms of changes in the values of the state variables. These definitions are useful because they facilitate the development of quantitative models, are easily understood, and are easily translated into actual management practices in the field.

Three types of primary models which are likely to be used in the NAMM model are mechanistic simulation models, statistical models, and models based upon intuitive approaches. The choice of the type of primary model to use in a given situation may depend upon both the kind and amount of information that is available. A statistical model may be the best choice when there is sufficient empirical data to derive the required functions for the joint production of resources. A mechanistic simulation model may be the best choice when one can define mechanisms related to the changes in the state variables of the system, and when sufficient data exists for validation of the model. Where little or no empirical data and only limited knowledge of mechanistic relationships exist, the model may be limited to one based upon an intuitive approach.

Mechanistic simulation models can provide time dependent estimates of the response of a system to management prescriptions. Such models represent an ecological system as a collection of compartments which are linked by flows of the material contained in the compartments. The dynamics of the flows are defined by a set of rate equations which are related to known or postulated biological and physical mechanisms. The rates of flow can be dependent upon information about the levels of material in the compartments of the system or related systems, as well as upon system independent factors such as temperature and insolation. A simulation model theoretically has the potential of mimicking the response of a system to almost any perturbation, i.e., the model system will respond in the same manner as the real system. However, the kind of knowledge required to construct such "ideal" models for ecological systems is generally lacking. Ecological simulation models are usually constructed using simplifications of the system, and thus their use is less flexible than that of an ideal model. Also, the methodology needed to produce simulation models is less well-defined than that for statistical models.

Statistical models define empirical relationships between state variables. Examples of techniques used to generate such models are multiple regression, time series analysis, and discriminant analysis. Often implicit in such models are assumptions about the functional form of the relationship between the variables. For example, a common assumption in regression analysis is that a dependent variable can be estimated from a linear combination of one or more independent variables. Except for models based upon time series analysis, most statistical models can provide only point estimates for state variables, i.e., the value of the variable at some fixed time. The accuracy of such an estimate is related to both the degree to which the assumptions used in the model are valid, and to the number of observations which are used to estimate the parameters of the model.

Models based upon intuitive approaches may be the best alternative in those situations where data is so sparse that neither simulation nor statistical models can be constructed. In this approach, point estimates or functional relationships of the response of state variables to various management prescriptions are derived from the opinions of "experts." These experts are people who are most familiar with the particular system being modeled. Thus, the intuitive approach derives quantitative functions or relationships for the joint production of resources from the "mental" models of the experts.

Prior to discussing the problems involved in creating the primary models, it may be helpful to list some of the attributes characteristic of an "ideal" primary model. It is unlikely that models having all of these characteristics are feasible. However, these attributes can be used as goals during the construction of primary models. For example, an ideal model would make predictions about the responses of the system to management prescriptions which are always correct where correct means that the model faithfully predicts that which would be observed in the field under the prescribed management. Models which produce estimates having large uncertainties are undesirable because such uncertainties can accummulate with the aggregation process used in the NAMM. An ideal model could accommodate any new management alternative, and any change in the system due to management. Only simulation models would be likely to fulfill this goal. Finally, certain practical aspects of the models are important. Ideal models would be inexpensive to operate, yet would be easy to design, construct, modify, maintain use, and transport from one computer to another.

The process of creating the primary models may be facilitated by a protocol or general approach to be followed. This protocol could help assure that the primary models would be the best models that could be constructed to fit the

overall objectives of the NAMM. One research problem to be attacked is to devise such a protocol. The protocol should address both the technical problems associated with building models and the organizational problems involved with the kind of interdisciplinary activity needed to build integrated, multiresource models.

As a general example of an approach that could be used, consider one that contains the following six basic steps:

1. The definition of the set of management prescriptions to be applied. These management prescriptions will define all the state variables that will be directly affected by the prescriptions.

2. The definition of the resources and other state variables which may act as constraints. State variables which may act as constraints might include the population size of any endangered species or the concentration of sediments in streams. These variables plus those from step 1 constitute a minimum set of state variables to be included in the primary models. Other state variables may be added to this list if they are important to the functioning of the system.

3. The assembly of all pertinent data and theory related to the variables and processes defined in steps 1 and 2. This step is important because it clarifies how much is known about the system and how much data is actually available for use in constructing the models.

4. The choice of whether to build a mechanistic simulation model, a statistical model, or an intuitive model. As stated earlier, this choice will be dependent upon the kind and amount of information that is available, i.e. upon Step 3. In some cases this choice may require that models of more than one type be constructed and compared.

5. The construction and documentation of the models. The construction of the models would include development of a mathematical model, and the conversion of those mathematical models into algorithms for generating quantitative estimates of the responses of the state variables. These algorithms would probably be coded for implementation on computers. The importance of documentation cannot be underestimated. Documentation provides the mechanism by which models can be efficiently modified and improved in accordance with the objectives of the NAMM.

6. Testing the adequacy of the models. The exact nature of this step is somewhat dependent on the type of model being tested. Simulation models and, to a certain extent, statistical and intuitive models will need to be verified and validated. Then the models can be used to try to determine whether there may be some management alternatives that have not yet been considered. If new management alternatives can be identified, then it may be necessary to return to step 1 and iterate through the entire process again. Once no new management options can be defined, error and sensitivity analyses of the models should be performed. The results of these analyses will provide a measure of the accuracy and dependability of the estimates, and help indicate those areas where further work on the model could make improvements.

A review of NAMM has identified a number of problems which need more research. Some of these problems, with a short discussion of each, will be listed below.

Problem: What can be done to facilitate the assembly of all pertinent data and theory related to the set of state variables used in the primary models?

The quality of the primary models will be highly dependent upon the quality and quantity of information used in their construction. A centralized, easily accessible, user-oriented data base system could be helpful in this regard. The documentation of previous modeling exercises on similar National Forests may be particularly helpful. The inclusion into the modeling activity at one forest of one or more people who have worked on models in another similar forest could be very useful. Such people would be familiar with much of the information available, may be able to point out potential problems and pitfalls, and may be able to help identify alternate management prescriptions.

Problem: What methods can be used for determining which of the three types of primary models would be most efficacious in a given situation?

In general, simulation models often require more information than do statistical models. This information usually consists of quantitative statements about mechanistic relationships and some data which can be used to validate the model. Statistical models, on the other hand, require little or no information about mechanistic relationships, but do require quantitative data of sufficient quantity and quality to permit empirical relationships to be derived. The intuitive models should be used only where data sufficient to construct either simulation or statistical models are lacking. Two criteria by which to compare alternative models are the amounts of uncertainty in their predictions and the accuracy of the predictions; the predictions must be both precise (little uncertainty) and accurate. Where levels of accuracy and precision are roughly equivalent between models of different types, other characteristics of the "ideal" primary model can be used as criteria for making a choice.

Problem: How can improvements in primary models be facilitated?

Improvements in the primary models are changes which result in a better achievement of the goals of the NAMM, and thus are changes which bring the primary models closer to the characteristics of the "ideal" primary model. Initially, improvements probably will be aimed primarily at increasing the precision and accuracy of the models. Such improvements may require the use of data from additional research, although much of the data used for testing accuracy of the models will result through time from application of different management prescriptions.

Error and sensitivity analyses may be useful in pointing out those areas of the model in which the most significant improvements can be made. An error analysis can provide estimates of the uncertainties of all pertinent output variables. Error analyses of the higher level models can be used to help identify those variables whose uncertainties have the greatest impact upon the objective functions of those models. Then a sensitivity analysis of the primary model can help identify the sources of uncertainty in the production estimates. Research which would allow such uncertainties to be reduced would thus be of the greatest benefit with respect to the goals of the NAMM. It is important to recognize that a large uncertainty in an economically unimportant product may be inconsequential compared to a much lower uncertainty in an economically important product if the management goal is to maximize economic value.

Another factor related to improving the models is the technical problem of making changes in the computer code. Since the people who wrote the code may not be the ones who will make changes, it is important to develop a protocol which will facilitate making these changes. Such

a protocol should specify both the form and detail of both internal and external documentation as well as certain standards for the coding of the computer programs. Internal documentation refers to comments placed within the body of the computer program, and external documentation refers to printed material, such as user and maintenance documents. Examples of standards which could be specified for the code are that the programs be written in FORTRAN conforming to the 1977 American National Standards Institutes requirements, and that the code be structured through the use of subprograms, indentation of "DO" loops, and limited use of "GO TO" statements. Such requirements probably would add little to the effort involved in coding the models initially, and could greatly reduce the effort required to make changes in the code at a later date. Such requirements can also insure that the models can be transferred from one computer system to another, if necessary.

Problem: How should primary models be validated?

An important goal of the NAMM approach is to produce the most accurate and precise estimates as are possible. As the basis upon which all higher level analyses are dependent, the primary models need to represent the responses of the system to management prescriptions in a realistic manner. Validation is a procedure by which the responses of the primary models are compared to the responses of the forest when subjected to management prescriptions. Thus, validation can often be reduced to a statistical analysis. However, in any such analysis it is important to define the purpose for which the model will be used, because the criteria by which the performance of the model is to be judged are often dependent upon this purpose (Welch et al. 1981). For example, suppose that a

model of the population dynamics of an insect pest has been constructed, and that this model characterizes the general trends in the population well, but is consistently wrong in actual predictions of insect numbers. Suppose this model is used to determine the best control strategy. If its use allows the right control decision to be made at least as often or more often than the best control strategy would be chosen otherwise, then the model should be considered as working well. On the other hand, if the model were to be used to predict actual numbers of insects, it would not be considered as working well.

Welch et al. (1981) list four considerations important in the evaluation of a management model: (1) will its use increase profits relative to current practice, (2) does it have negligible probability of leading to disasterous results, (3) is it compatible with other management practices, and (4) is it easy to understand? These considerations, or variations of them, should be applicable to both the primary models and the NAMM as a whole.

Problem: When statistical or simulation models are to be built, what can be done to facilitate the construction of the models?

To achieve the major goals of the NAMM, the quality of primary models should reflect the quality and quantity of data available for use in their construction. The major obstacle which may be encountered is a lack of expertise in quantitative modeling, or expertise in only one kind of modeling. If simulation modeling is not familiar to those who are designing the primary models, then efforts may be directed toward building statistical models only, and vice versa. Thus the type of model best suited for the situation may not be developed. This problem may be reduced by providing tools which help simplify the model building procedure,

by providing expertise on how to use the tools, and by providing a methodology by which conceptual models can be transformed into mathematical models. For example, one part of the methodology might be to use a workshop to teach modeling techniques. This workshop could be supervised and taught by a small team of people having expertise in modeling. Such a team could travel from forest to forest to organize and initiate modeling activities. In addition, this team could help transfer information about specific modeling approaches used in other, similar forests.

The kinds of tools which could be used to simplify modeling may include printed materials, such as a general primer of modeling techniques and other reference materials, and computer software tools, such as a data base system, statistical and mathematical routines, and a simulation language or pre-compilers.

Problem: When intuitive models are to be used, what methods should be used to query the "experts" in order to give the best results?

Traditionally, intuitive models have been generated using a Delphi approach or some similar method. Although such techniques can work well, their use must be well planned. In developing a methodology to develop intuitive models, at least five questions should be considered: (1) how should the "experts" be chosen, (2) how should questions be posed in order to get estimates of joint production of renewable resources rather than estimates of independent productions, (3) how can obvious conflicts between intuitive models from different sources be resolved, (4) how can uncertainties in the results of the models be estimated, and (5) how can models for new alternative management prescriptions be developed which are not biased by previous modeling exercises.

Problem: What methodology can be used to define subunits within a forest which will be consistent with the assumptions of homogeneity that are implicit in many of the models.

One assumption of the mathematical programming techniques used in the forest level models is that the land to which a management prescription is applied will respond in a homogeneous manner to that prescription, i.e., one acre of land in the unit is functionally identical to any other acre in that land unit. In an effort to conform with this assumption, forests can be subdivided into smaller more homogeneous units. Such subunits previously have been called Analysis Areas. The method used to define Analysis Areas was to a priori define the factors to which the system was sensitive, and then choose areas for which those factors appeared relatively constant. The problems which can arise using this method are that the conceptual or mental models used to define the sensitive factors are usually ill-defined or "fuzzy," that the mental models used are usually not complex enough to handle joint production estimates, and that such models are particularly sensitive to personal biases. Perhaps a better way to subdivide a forest would be to construct the primary models, and then use sensitivity analysis techniques to identify the parameters to which the output variables are most sensitive. Then these variables can be used to subdivide the forest into areas which are likely to be homogeneous with respect to the responses of the models.

Problem: What is the best way to model production on non-NFS lands?

This problem deals with the fact that non-NFS lands are under diverse managements, and that sub-units within these lands are most often defined by political rather than ecological boundaries. To consider

each management unit separately would be realistically impossible. Thus, primary models for non-NFS lands will be much less resolute than those for NFS lands. In addition, the management of the non-NFS lands can be defined only by general assumptions, since no direct control of these lands by the National Forest Service exists. Thus, any estimates of production on the non-NFS lands are likely to have large uncertainties. It is unlikely that simulation modeling will be useful in such a situation. Statistical models based upon long term trends may provide the most useable information. Given a large enough data base, time-series models could be useful in describing long term trends in production.

Problem: What is the best way to model the production of resources on NFS lands when that production is dependent upon the land use practices on non-NFS lands?

As an example of a situation of this type, consider estimating the production of elk in a herd which utilizes both NFS and non-NFS lands. A management prescription which affects winter forage may be hard to correlate with a response in the population size of the elk if their non-winter range lies primarily outside of the NFS lands. This apparent independence can arise because land use practices on non-NFS lands also influence the size of the population. In such a situation, it may be best to consider both NFS and non-NFS lands in the primary model. Alternate scenarios could be devised for changes in the land use practices on non-NFS lands. An estimate of the uncertainty in the population size of elk would then include both the uncertainty of the parameters of the model and the effects that the alternate scenarios have upon the population estimates. The effects of the alternate scenarios could be weighted by the probability that such scenarios might occur.

Problem: What techniques can be used to perform error and sensitivity analyses on the primary models.

Error and sensitivity analyses of simulation models are usually very similar from the standpoint of the data required. In either analysis, it is usually necessary to run numerous simulations. In each simulation, each of the parameter values is selected using a pseudo-random number generator from a distribution which describes the uncertainty for that parameter. A distribution for the resulting uncertainty in each state variable then can be constructed from the results of all the simulations. A sensitivity analysis can be done using the same set of simulated data by correlating changes in parameter values with changes in the state variables of interest. A partial correlation analysis of these data, or a rank-transformed data, has been found to be useful in these analyses. If only sensitivity analyses are to be done, the total number of simulations, and hence the expense, can be reduced by using a stratified sampling scheme in selecting the parameter values. A Latin-Hypercube design (McKay et al. 1979) has been found to work well in this regard.

Both the source of uncertainties and their effect upon the dependent variable can usually be obtained for statistical models. For example, in multiple regression analysis, one can find the proportion of the total variance accounted for by each independent variable (sensitivity) and an estimate of the confidence interval around any legitimate value of the dependent variable (error analysis).

The intuitive models are likely to pose the greatest problems in either error or sensitivity analyses. It may be possible to estimate uncertainties in predictions of these models by having the individuals who provided the models put some sort of confidence intervals on their estimates. It may then be possible to derive an estimate of the uncertainty in the outputs of the primary model from the individual estimates of uncertainty. The development of techniques to do error and sensitivity analyses on intuitive models may require considerable research.

Secondary Models

The NAMM model is designed to serve a dual role: to aggregate information about the potential productivity of resources from both NFS and non-NFS lands, and to help choose management plans to be applied to NFS lands which will best meet the goals set for resource production. The decision-making role of NAMM is facilitated by use of mathematical programming models to evaluate alternative management plans at the national, regional, and forest levels. Such decisions are based upon the economic analysis of the production of resources in the National Forests. These economic analyses are dependent, in turn, on the predictions of the expected production, as opposed to the potential production, of resources on non-NFS lands. Thus the Regional Alternative Generator (RAG) model must have information about resource production for both NFS and non-NFS lands.

In the NAMM, Linear Programming models, such as FORPLAN, will be used in the economic analyses of management alternatives to be applied to the National Forests. Theoretically, models similar in concept to the FORPLAN models could be constructed to estimate production of resources on non-NFS lands. However,

the detail of such models would require that there be an LP model and its associated primary models for each ownership in the non-NFS lands. Not only would the costs of creation and operation of these models be prohibitive, but the utility of such models would be limited. Such models could be used to assess the potential for production of resources on non-NFS lands, but to extract an estimate of the production actually to be expected would require that the Forest Service predict management decisions to be implemented by the individual owners. Since ownership specific information is probably not required for either the assessment of potential production or the estimated of expected production of resources from non-NFS lands, then the models for non-NFS lands could be more generalized in nature, i.e., they would aggregate across ownerships.

There are at least two approaches to use in formulating the models for non-NFS lands. In one, the future production of resources on non-NFS lands would be estimated by using a model which is based upon the past behavior of production of those resources. Such a model could be formulated as a statistical, time-series model, and thus would not require the use of additional primary models. In this sense, such a model could be considered a primary model, although it would probably incorporate both economic and ecological variables. One assumption in the use of such a model is that those variables which influence future production are adequately represented in the available data base. New technologies, new management practices, or significant alterations in management practices would reduce the predictive capabilities of such a model, at least until enough new data was collected to allow the model to be reformulated. The effects of any incentive programs sponsored by the Forest Service might be incorporated into such a model provided sufficient data existed to show a correlation between the production of resources and some measure of the incentives.

A second approach to use in modeling the production of resources on non-NFS lands would be to consider the non-NFS lands in a region as a whole. Primary models would be designed to estimate production of resources at this level of resolution, and a single LP model could be used to aggregate the information and pass it upwards to the RAG. The data base (primary models) for the NIMRUM model has been suggested as a basis upon which to design the LP models for the non-NFS lands in each region. Assuming that both models can be constructed, and that they operate in a valid manner, then the predictions of the model based upon past behavior should lie within the range of predictions of the LP model for non-NFS lands.

In practice, the use of both kinds of models for non-NFS lands would have value. On the one hand, the past behavior model may provide the best information on which to base management plans for the National Forests, since that model would incorporate a mechanism to predict the management actions taken on non-NFS lands. On the other hand, the NIMRUM type models can provide information which may indicate how a better solution to meeting the National and Regional objectives could be obtained by managing non-NFS lands in specified ways. This information could then be used to help develop incentive programs for state and private ownerships.

Problem: How can improvements in the mathematical programming models be facilitated?

An important goal in the development of the NAMM is to define mechanisms by which the overall structure of the NAMM can be improved, where improvements are defined as changes which result in a better achievement of the goals of the NAMM. The NAMM integrates both the ecology and the economics of resource production. However, improvements in the ecological aspects of the NAMM will result primarily from improvements in the primary models, whereas improvements in the economic aspects will be reflected by changes in the secondary, mathematical programming models. As discussed under improvements in the primary models, initial improvements in the economic models will be aimed primarily at increasing the precision and accuracy of the models. Error and sensitivity analyses can be important tools for identifying those parts of the model in which improvements need to be made with regard to precision. These analyses can suggest where improvement in the primary models need to be made, as well as where improvements in the secondary models could be helpful. Validation proceedings will be required as checks on the accuracy of the model predictions. Such analyses will need to consider factors related to both the predictions of the production of resources (the supply side of the economic models) and the predictions of the demand for those resources.

Problem: What should be done if there are National Forests in a region for which no FORPLAN-type models exist?

Given that a management plan must be developed for every National Forest, there appear to be only two options to resolve the problem of a missing FORPLAN: (1) develop a plan for the forest independently from the

NAMM planning process, or (2) provide help in constructing a model for that forest. In the case that the former option is chosen, perhaps production estimates could be obtained using intuitive or other primary models. These estimates for the production of resource could then be added to the estimates from non-NFS lands to help compensate for the omission of the model for that forest in the NAMM. If the second option is chosen, it may be possible to reduce the effort required to construct a model for the forest by using a modification of a FORPLAN and its associated primary models from a similar forest in the region.

Problem: What can be done to correct for unexpected changes in the demand for resources or the supply of resources from non-NFS lands when such changes may alter the choice of management plans to be implemented on NFS lands.

The choice of management plans to be implemented on NFS lands is determined on the basis of predictions of both the demand for resources and the supply of those resources from non-NFS lands. It would seem to be beneficial to reveiw those management plans through time as data on the actual supply and demand situation becomes available. Such reviews could be scheduled at regular intervals or when unexpected changes in the economy occur. A mechanism for making corrections in the choice of management plans in NAMM could be especially important if incentive plans offered by the Forest Service modified the supply of resources coming from non-NFS lands to a degree not accounted for in the models for non-NFS lands.

Problem: What techniques can be used to perform error and sensitivity analyses on the mathematical programming models?

The rationale for doing error and sensitivity analyses on the economic models is the same as that for the primary models, i.e., to show where uncertainties in model predictions are arising, and to help indicate where research can be done to improve the models. It appears that techniques for such analyses on mathematical programming models are not well defined. Research may be required to develop the methodology for doing such analyses. Perhaps Monte Carlo methods based upon uncertainties in the model parameters would suffice, in which case the Latin-Hypercube design for sensitivity analyses would be useful.

Problem: How can errors be detected in the estimation of production of resources or in choice of management plans due to the stepwise aggregation approach of the NAMM?

In moving from the lowest level to the national level in the NAMM hierarchy, the set of management plans chosen to best achieve a defined goal may be suboptimal compared to the set of plans that would be chosen if all the intermediate models could be eliminated. This suboptimability can arise because (1) the management areas covered by the economic (LP) models are assumed to be independent, (2) there may be differences between management areas in the range of management options considered, and (3) the management plans at each level represent discete choices. If feasible, it would be informative to build a single LP model for all the NFS and non-NFS lands in a region. The set of management prescriptions chosen for the analysis areas in the single model could then be compared to the set chosen using the NAMM approach, and the degree of optimality achieved in the two methods could be compared.

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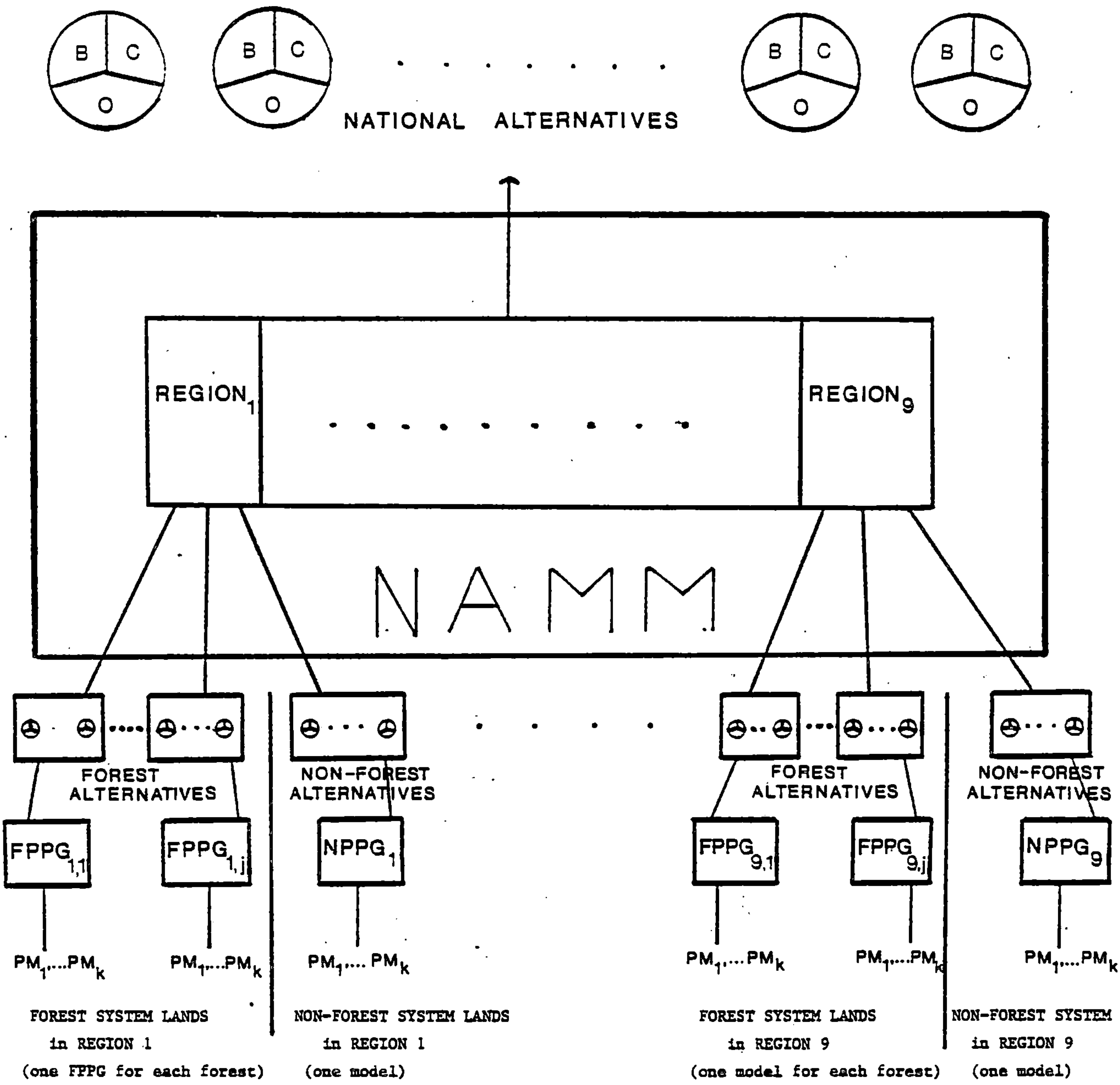

KEY: NAMM = NATIONAL ASSESSMENT MULTIRESOURCE MODEL

$FPPG_{i,j}$ = Forest System Production Possibilities Generator for the j^{th} Forest in the i^{th} Region

$NPPG_i$ = Non-Forest System Production Possibilities Generator for the i^{th} Region

$PM_1,\ldots,PM_k$ = Primary models predicting production response to management

ALTERNATIVES CONSIST OF RESOURCE OUTPUTS (O), COSTS (C), AND BENEFITS (B)

Figure 1. The NAMM model.